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Aqua-Logiq (Intelligent water logic)

Utilises logic-based thresholds derived from AI and biology,
rather than timers or guesswork.

Final Project Report
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1. Introduction

Across Central Asia and beyond, water management is entering a critical phase. Climate volatility, ageing infrastructure, and declining soil fertility are converging into a perfect storm — one that demands smarter, leaner, and more responsive agricultural technologies. In Uzbekistan, where over 90% of water withdrawals are allocated to agriculture, even a 10% improvement in irrigation efficiency could have a profound ecological and economic impact.

Yet most irrigation systems still rely on outdated logic: a fixed schedule, a predefined dosage, and a focus on crop performance in isolation. These systems often ignore the soil's living ecosystem, the atmospheric conditions above, and the feedback signals emitted by plants under stress. Even many “smart” systems available today merely automate pre-set intervals or use basic soil moisture thresholds — reactive rather than intelligent.

AquaLogiq proposes a new direction.

Rather than focusing on when to irrigate, AquaLogiq asks why — and whether that act will enhance or harm the delicate balance between plant, soil, and climate. It is not an automation tool, but an irrigation reasoning engine that draws on multi-dimensional inputs: root signals, fungal network activity, microclimate metrics, and evapotranspiration models, to decide how water should be used responsibly.

This system rests on three pillars:

- **Biological Awareness:** It interprets plant and microbial signals as early indicators of stress or readiness, using bioelectrical sensors and biological activity indices.
- **Environmental Sensitivity:** It incorporates real-time data from low-cost atmospheric mesh nodes — detecting dew, vapor pressure deficit, and radiation balance — to avoid unnecessary or poorly timed irrigation.
- **Logical Decision-Making:** It uses a modular AI framework (the AquaLogiq Engine) that weighs all inputs before suggesting water volumes, time slots, and delivery modes — tuned to the needs of both crops and soil.

The result is a system that does not simply “know when it’s dry,” but understands when irrigation is beneficial versus when it is disruptive.

Consider a field of onions in Navoi, sown on loamy soil during an unusually hot May. Conventional drip irrigation may apply water every 48 hours by default. AquaLogiq, on the other hand, observes that the root zone remains active due to overnight dew accumulation, fungal channels remain intact, and the expected transpiration rate is within tolerance. It defers irrigation by 36 hours, saving hundreds of liters and preserving fungal integrity.

But AquaLogiq isn’t limited to large farms with high-tech infrastructure. It was conceived with local farmers in mind. The system is built from inexpensive, modular hardware — RootSense probes, MycoTrace patches, and AirMesh weather heads — all powered by solar panels and connected through a simple GSM or LoRa signal. Data is processed locally by an edge-computer unit that can operate entirely offline.

Outputs are then sent directly to farmers via SMS, app, or even audio prompts. Messages like:

“Water Field 2 - 180 m³ from 6:00 to 8:00 - optimal ET conditions.”

Or:

“Defer irrigation. Root zone stable. Dew formation is sufficient.”

These instructions can be followed without needing digital literacy or high-speed internet. Older farmers can receive printed turn calendars, while youth collect and upload field logs — blending digital innovation with community knowledge.

Another key principle of AquaLogiq is regenerative priority. Unlike yield-focused systems, AquaLogiq includes a soil memory module. It tracks overwatering events, microbial loss, and nutrient washout over time. The goal is not just to maximize harvest this season, but to ensure next year’s soil is healthier than this year’s.

The AquaLogiq system is adaptable for:

- Rotational cotton-legume fields in Sirdaryo
- Fruit orchards in Fergana that rely on gravity-fed systems
- Salinity-stressed melon zones in Karakalpakstan

- Greenhouse tunnels in Tashkent suburbs

Each context brings different variables, and AquaLogiq is structured to learn from each one. Its decision engine is trained on regional climate patterns and refined with local calibration, meaning no two installations behave the same. This makes it resilient and locally responsive, not a one-size-fits-all solution.

Moreover, AquaLogiq can contribute to larger sustainability goals. By documenting improvements in water-use efficiency, soil carbon content, and nutrient retention, the system generates evidence for carbon crediting and green financing. It turns irrigation into not just a farm decision, but a contribution to national resilience and global sustainability metrics.

In summary, AquaLogiq is not just a new irrigation system. It is a shift in thinking — away from fixed rules, and toward adaptive logic. It restores decision-making to the soil and the plant, enabling farmers to work with nature's signals instead of against them.

The next sections of this report will present AquaLogiq's architecture, core technologies, field deployment strategies, and measurable outcomes. Together, they will demonstrate how intelligent water use is not just possible, but urgently necessary for the future of agriculture in Uzbekistan and beyond.

2. Challenges in Traditional Irrigation

2.1 Legacy Systems in a Changing Climate

Irrigation practices in Central Asia — particularly Uzbekistan — are shaped by decades of dependence on extensive surface water infrastructure. The vast canal systems developed in the 20th century remain the primary means of distributing water to agricultural lands. While these networks were initially effective at supplying large-scale cotton and wheat farms, they were never designed for climate resilience, crop diversification, or ecological sensitivity.

The result is a system that delivers bulk water but lacks precision, sustainability, and flexibility. As climate variability increases — with hotter summers, erratic rainfall, and prolonged drought periods — the inability to adapt water delivery on a micro scale is becoming a critical bottleneck.

Traditional canal irrigation, in particular, suffers from water loss at every level: leakage from unlined channels, evaporation from open surfaces, and uncontrolled runoff in fields. The reliance on fixed water delivery schedules means that irrigation is applied regardless of whether crops need it or not, leading to overwatering in some areas and under-irrigation in others.

2.2 Uniformity Over Specificity

One of the most significant limitations of traditional irrigation systems is the assumption that “one size fits all.” Watering schedules are typically determined by crop type and season alone, ignoring key variables such as:

Soil type and structure;

- Microtopography of the field;
- Crop variety and root depth;
- Prevailing wind and radiation levels;
- Soil microbial health and water retention capacity;

For example, two fields growing onions may receive identical irrigation volumes, yet one sits on sandy loam and the other on clay-rich soil. The sandy field may lose water to deep percolation, while the clay field may become waterlogged — neither outcome is optimal, and both contribute to wasted resources and lost productivity.

This lack of site-specific logic is compounded by the absence of field-level sensors or diagnostics. Farmers often rely on visual cues — such as wilting or surface dryness — to determine irrigation needs, by which time crops may already be under stress.

2.3 Absence of Biological Feedback

A deeper problem with traditional systems is their neglect of the biological dimension of agriculture. Soils are not inert media — they are living ecosystems composed of microbes, fungi, roots, and organic matter. These living systems play a critical role in water storage, nutrient cycling, and plant health.

Over time, indiscriminate irrigation erodes this biological integrity. Excess water reduces oxygen availability, leading to anaerobic conditions that suppress beneficial organisms. Soluble nutrients like

nitrogen and potassium are leached away, and soil structure degrades due to the loss of root-microbe interactions.

Yet most irrigation logic still operates as if these dynamics do not exist. There are no provisions to measure or respond to soil respiration, microbial balance, or fungal activity. In effect, the system treats water as an input and the soil as a pipe, rather than a partner in the growth process.

2.4 Reactive Rather Than Predictive

Perhaps the most systemic flaw in current irrigation practices is their reactive nature. Watering occurs only when symptoms of stress appear: drooping leaves, dry soil surfaces, or delayed flowering. By this stage, the plant has already suffered a physiological setback, and yield potential is compromised.

There is no mechanism in traditional systems to forecast irrigation needs based on forward-looking data such as:

- Projected evapotranspiration;
- Wind and solar exposure;
- Nocturnal cooling rates;
- Root-zone activity or early water stress signalling;

Without predictive capabilities, farmers either irrigate too late or apply water “just in case,” leading to inefficient outcomes in both scenarios.

2.5 Lack of Integration with Modern Tools

While mobile connectivity, satellite data, and local weather sensors are increasingly available, most irrigation systems in the region operate independently of these innovations. There is little integration between water management tools and digital platforms. Even when data is available (e.g., through hydromet services), it is rarely translated into actionable recommendations for farmers.

This disconnect is exacerbated by digital literacy barriers and the lack of user-friendly interfaces in Uzbek, Russian, or other regional languages. Many older farmers are unfamiliar with app-based systems, and extension services cannot often bridge the gap between sensor data and field practice.

2.6 Economic and Environmental Costs

The consequences of traditional irrigation inefficiencies are not theoretical — they are visible across the landscape:

- Waterlogging and salinisation affect over 50% of irrigated land in some Uzbek provinces.
- Aquifer depletion is accelerating in areas where pumping supplements canal water.
- Energy waste occurs through the overuse of diesel or electric pumps.
- Yield variability remains high even within small geographic clusters, due to water imbalance.

These costs ripple into the national economy, reducing food security, farmer income, and the effectiveness of public water infrastructure investments.

2.7 Community and Equity Issues

Lastly, traditional irrigation frameworks often create inequities within farming communities. When water is distributed on a fixed rotation, upstream users may overuse their share, leaving downstream farmers without an adequate supply. Conflicts arise not only over timing and volume but also over responsibility for maintenance, cost-sharing, and fairness.

Moreover, women, youth, and smallholder farmers may have less voice in how water decisions are made, especially when those decisions rely on technical language or non-transparent rules.

2.8 Conclusion of Section

In summary, the traditional irrigation model — while historically effective in increasing production — is now mismatched to the ecological, climatic, and social realities of modern agriculture. It fails to account for complexity, diversity, and the intelligence embedded in natural systems. To move forward, we must adopt irrigation approaches that are not only precise but also responsive, regenerative, and just.

AquaLogiq is proposed as one such approach — an irrigation logic system designed to overcome these challenges by grounding decisions

in biology, forecasting, and local ownership. The next section will outline the technical architecture and components that make this possible.

3. System Overview: Architecture, Operation, and Cost Structure

3.1 Core Design Philosophy

The AquaLogiq system is not a device — it is an intelligent irrigation framework built to interpret and respond to complex, field-level signals. It leverages a combination of biological inputs, environmental monitoring, and AI-supported logic to determine if, when, and how much water a crop truly requires. This decision is based not only on soil moisture but also on microbial activity, crop physiology, and microclimatic energy balances.

At its core, AquaLogiq is modular, solar-powered, and capable of functioning entirely offline, making it highly adaptable to the diverse landscapes and digital limitations of Uzbekistan and neighbouring countries.

3.2 System Components

3.3 System Operation Logic

The AquaLogiq system operates in four stages:

Data Collection:

- RootSense probes detect electrochemical activity linked to plant hydration status.
- MycoTrace monitors fungal respiration and carbon exchange behavior.
- AirMesh gathers humidity, dew, wind, temperature, and solar radiation.

Predictive Modelling:

- All input data is interpreted locally by EdgeLogic using seasonal ET_0 curves, NDVI overlays (from Sentinel-2), and historical field patterns.
- Soil profile and crop variety are factored into machine-learning irrigation scenarios.

Decision Output:

- The system determines a water window (time + volume).
- Farmers receive notifications such as:
"Water Field #3 on Thursday from 5:00 to 8:00 (170 m³ recommended)."

Feedback Logging:

* A simplified daily log tracks actual application, microbial response, and optional farmer notes.

3.4 Deployment Configuration

A typical 5-hectare unit (suitable for cotton, vegetables, or wheat) includes:

- 10 RootSense probes (2 per hectare)
- 5 MycoTrace patches
- 2 AirMesh weather stations
- 1 EdgeLogic controller (with solar battery and housing)
- SMS + printed dashboard kit (per farmer group)

3.5 Estimated Costs (Pilot Scale)

Annual maintenance cost: ~\$100-150 (mainly battery, calibration, cleaning)

Lifetime: 4-5 years (average under field conditions)

3.6 Advantages Over Competing Technologies

3.7 Scalability and Customization

Can be scaled up to 100+ hectares with LoRa-based daisy chaining.

Field nodes are firmware-upgradable.

Interface supports voice notification add-ons for low-literacy regions.

Future modules include salinity detection and carbon sequestration monitoring.

3.8 Summary

The AquaLogiq system is more than a tool — it's a strategy. By blending local knowledge with biological indicators and predictive data, it redefines irrigation from an extractive utility to a soil-regenerative service. The low cost per hectare and modular nature allows even smallholder farmers to adopt it, and government support can accelerate adoption through digital extension programs and performance-linked subsidies.

4. Deployment in Uzbek Fields

4.1 Overview: Deployment Context

Uzbekistan's agricultural fields vary dramatically in terms of soil type, irrigation methods, cropping patterns, and community structure. Effective deployment of AquaLogiq requires local adaptation of hardware placement, training methods, and interface language.

Three main agro-ecological zones have been identified for phased deployment:

- Sirdaryo & Jizzakh Regions (irrigated plains with cereal-legume rotations)
- Karakalpakstan (Amudarya basin) (salinity-affected fields with melons, cotton)
- Fergana Valley & Namangan (intensive horticulture and fruit production)

Each zone presents distinct constraints and opportunities for pilot testing, farmer engagement, and performance benchmarking.